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Diurnal freeze-thaw frequencies in selected regions of the high latitudes

July 1984

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U.S. ARMY CORPS OF ENGINEERS
ENGINEER TOPOGRAPHIC LABORATORIES
FORT BELVOIR, VIRGINIA 22060-5546

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this study is to provide information on the incidence of daily freezing conditions, i.e., frost days (min $\leq 0°C$), ice days (max $\leq 0°C$), and freeze-thaw days (min $\leq 0°C$ max $> 0°C$), per month or year throughout Alaska, Eastern Siberia, Iceland, and Greenland. Tables are provided of the above parameters. In addition, linear regression equations were developed for each area for deriving the above information from ordinary climatic data. Station models of percent days per month with freeze-thaw throughout the year are also given for a range of climates in the regions indicated as well as for several German stations representing a range of elevation. Another set of models shows that the percent freeze-thaw per month could be expressed

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) as a function of mean monthly temperature. The constants for the latter (sine) function reflect the continentality of the station. The various models presented demonstrate the relationship between daily freezing conditions and the temperature regime. The results should improve understanding of periglacial activity and provide a means of predicting possible climatic effects on the construction of buildings, roads, and airport runways.

PREFACE

The impetus for an investigation of the world-wide incidence of daily freezing conditions, especially diurnal freeze-thaw cycles, was generated by requests from several Army agencies, including the Test and Evaluation Command (TECOM). Freeze-thaw cycles have numerous applications of military significance, particularly with regard to off-road mobility, vulnerability of roofing, and equipment malfunction. Climatological studies of this nature provide weather support for Field Army tactical operations.

This work was accomplished under Project 4A161102AT24, Task C, Work Unit 001, "Relationship between Environmental Factors and Materiel Design Problems."

Appreciation is extended to the Environmental Technical Applications Center, Asheville, N.C., for providing processed data for many stations in the Northern Hemisphere; to Mark Schroeder, Mary McClarnon, Cedric Key, and Lee Morkes, U.S. Army Engineer Topographic Laboratories (ETL), for computer and drafting assistance; and to my colleagues in the Battlefield Environmental Effects Group, ETL, for their helpful suggestions.

The work was performed under the supervision of D. W. Dery, Chief, Battlefield Environmental Effects Group (BEEG), R. J. Orsinger, Chief, Land Combat Systems Division, and W. E. Boge, Director, Geographical Sciences Laboratory.

Col Edward K. Wintz, CE was Commander and Director and Mr. Walter E. Boge, was Technical Director of the U.S. Army Engineer Topographic Laboratories during the report preparation.

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DIURNAL FREEZE-THAW FREQUENCIES
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INTRODUCTION

The impact of diurnal freeze-thaw cycles on soils, rocks, roadbeds, and construction materials is of much concern to the agriculturist, hydrologist, geologist, and transportation or construction engineer. As noted by Troll, such alternation of freezing and thawing affects the particular size structure of the soil, causes erosion, runoff, or flooding, and reduces the bearing strength of the surface layer.[1] The vulnerability of the ground depends, among other variables, on the amount of available moisture and whether the ground is bare or is covered, as with vegetation, ice, or snow.

The surface covering affects the albedo, which in turn is largely responsible for local differences in extreme temperatures, i.e.,the daily maximum and minimum, the determining factors of daily freeze-thaw. Daily freezing conditions may be defined as consisting of frost days (min $\leqslant 0^{\circ}C$), ice days (max $\leqslant 0^{\circ}C$), and freeze-thaw days (min $\leqslant 0^{\circ}C$, max $> 0^{\circ}C$). The interrelationship among these three variables forms the basis of this study. The principal question is: What incidence of diural freeze-thaw cycles may be expected at a given site per given interval of time?

Much of the information in this report was presented at the Fourth International Conference on Permafrost, held 18 through 22, July 1983 at Fairbanks, Alaska. The conference paper was entitled "Diurnal Freeze-Thaw Frequencies in the High Latitudes: A Climatological Guide."

Information is provided on daily freezing conditions in the permafrost and contiguous regions of Alaska, Eastern Siberia, Iceland, and Greenland. Also included are several German stations, representing a range of elevations, in order to compare the effects of altitude with those of latitude. As in an earlier study,[2] a number of guides are offered for estimating the respective frequencies of frost days, ice days, and freeze-thaw days per month or year for a given site from routine climatological parameters.

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[1] C. Troll. "Structure Soils, Solifluction, and Frost Climates of the Earth," SIPRE Translation, 1958.

[2] R.L. Wexler. "A General Climatological Guide to Daily Freezing Conditions: Frost Days, Ice Days, and Freeze-Thaw Days." U.S. Army Corps of Engineers, Fort Belvoir, Virginia. ETL-0287, AD-A116 771, 1982.

BACKGROUND

The geographical distribution of the annual number of diurnal freeze-thaw cycles has been determined for various countries or sections: United States, Canada, Poland, Japan, the Arctic, Europe, and the U.S.S.R.* Annual or monthly frequencies of frost days, ice days, and freeze-thaw days have been correlated respectively with mean daily minimum temperatures, mean daily maximum temperatures, or a combination of both.**

DATA

Frequencies of diurnal freeze-thaw cycles are not readily available. Many climatic summaries list frost days, but few list ice days. In the past, information on freeze-thaw cycles has been simulated (Hastings,[3] Visher[4]). In this report, all the analyses are based on observations of daily maximum and minimum temperatures, the data for which were obtained from a variety of sources, mainly the U.S. Department of Commerce,[5] the Danske Meteorologisk Institute,[6] and the U.S. Air Force Environmental Technical Applications Center.[7] All the temperatures referred to in this report were from standard weather shelters at 1.5 to 1.8 meters above ground (screen height).

*Refer to the References for information on diurnal freeze-thaw cycles: Fraser, 1959; Hastings, 1961; Hershfield, 1972; Pelko, 1970; Russell, 1943; Shitara, 1970; Visher, 1945; Wexler, 1982; and Williams, 1964

** Refer to the References for information on frequencies: Fraser, 1959; Hershfield, 1972; Shitara, 1970; and Wexler, 1982

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[3]A.D. Hastings. "Atlas of Arctic Environment." Headquarters Quartermaster Research and Engineering Command, Natick, Massachusetts. 1961.

[4]S.S Visher. "Climatic Maps of Geologic Interest." *Bulletin of the Geologic Society of America.* vol. 56, pp. 713–736, 1945.

[5]U.S. Department of Commerce. "Local Climatological Data Annual Summary with Comparative Data (stations in Alaska)." 1980.

[6]Danske Meteorologiske Institute, Meteorologisk Arbog, Part 2, Greenland. 1947–1965.

[7]U.S. Air Force Environmental Technical Applications Center.

FROST DAYS AND ICE DAYS

For a network of stations in a given region, summarized observations per month and year were obtained for the mean daily minimum temperature, N; the mean daily maximum temperature, M; the number of frost days, F; and the number of ice days, I. From these observations, simple linear regression models were determined such that F may be derived from N, and I may be derived from M for any site within the specified region per given interval of time. Figure 1 gives examples of these regression plots for annual data for Alaska, Eastern Siberia, Iceland, and Greenland. Figure 2 contains similar plots for monthly data for May (Greenland) and April (the other areas). All the days of the month were usually below freezing if the mean maximum temperature was $<-6^{\circ}C$ and above freezing if the mean minimum temperature was $>6^{\circ}C$. The corresponding regression equations are

$$F = a_1 + b_1N \tag{1}$$

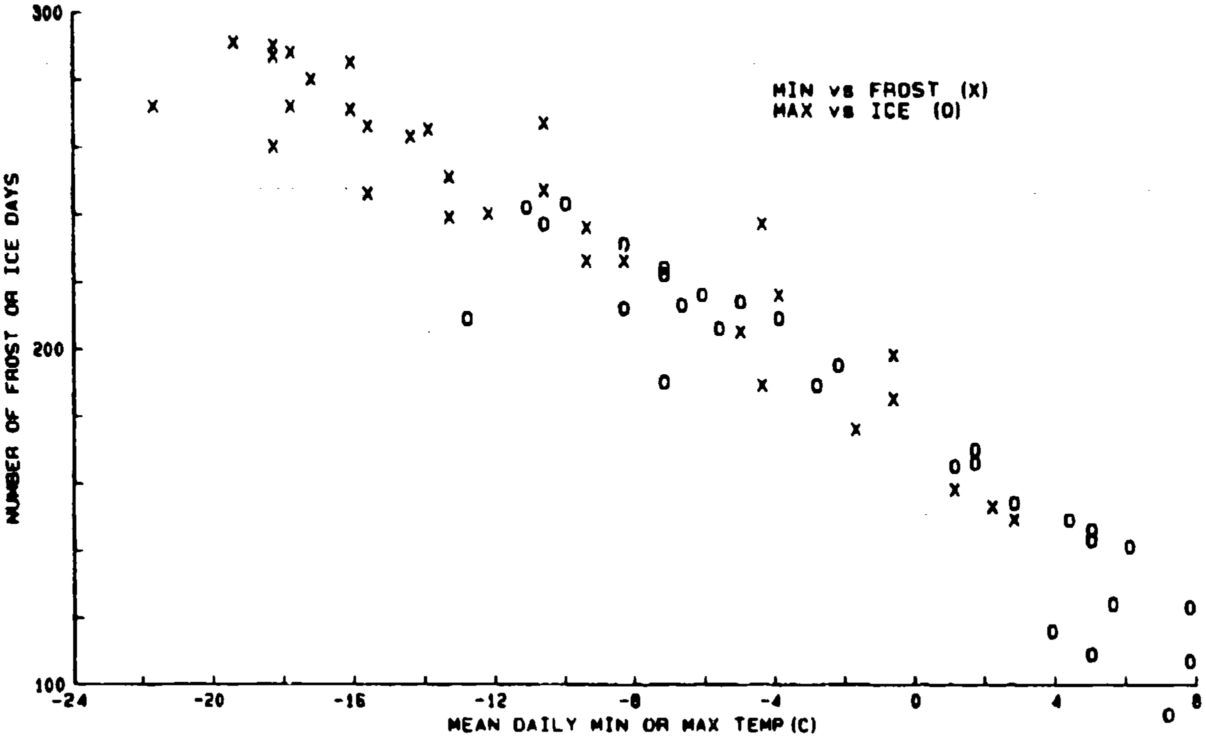
and

$$I = a_2 + b_2M \tag{2}$$

The parameters a and b depend on the data. They serve as constants for any data set. Table 1 lists values of these constants for monthly and annual data for the above regions. The coefficient of determination, r^2, for the various equations (implied in table 1) ranged from 0.50 to 0.99 with few exceptions: 0.24 for February, Greenland, and 0.36 for March, Eastern Siberia. (The value of r^2 indicates the quality of fit between F and N or I and M: 1.0 = excellent fit, 0 = no fit.)

Stations were chosen in a given area so as to represent as large a range of temperature as possible. The equations (1) and (2) are therefore applicable throughout the entire area, with only M and N changing from station to station.

ANNUAL DATA FOR SIBERIA



ANNUAL DATA FOR ALASKA

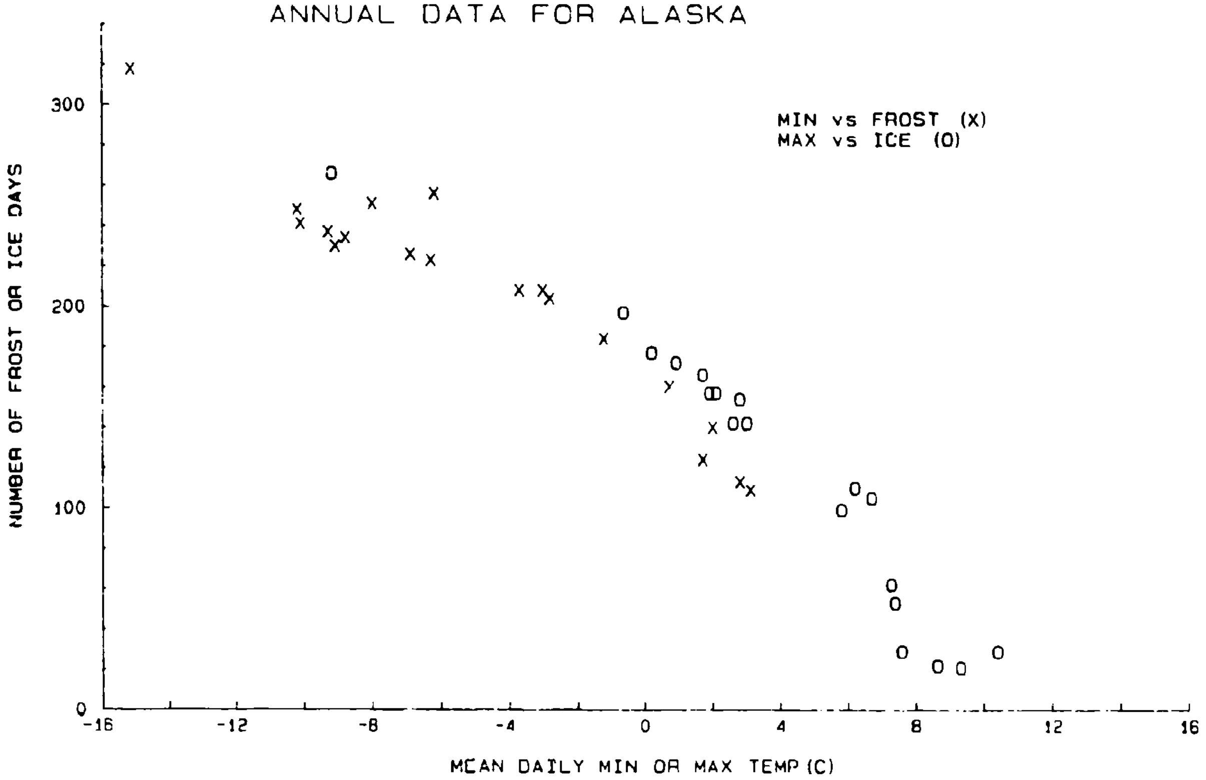
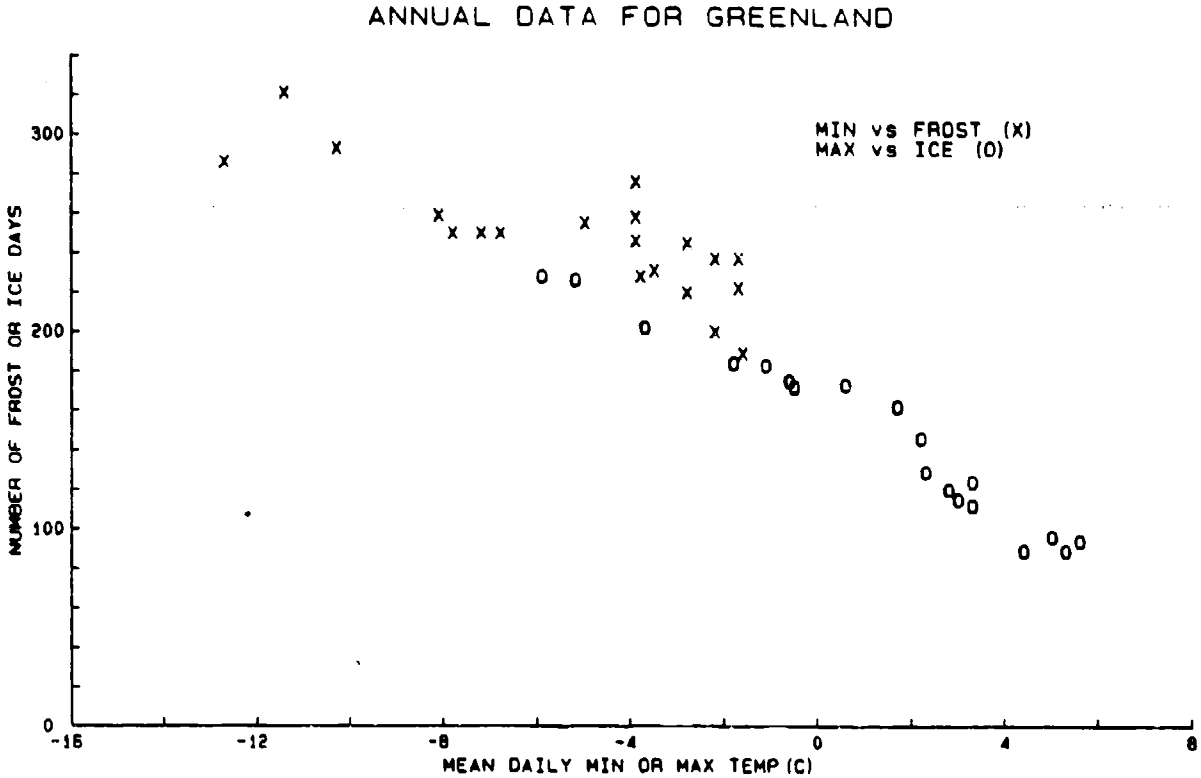


Figure 1. Annual Data for Selected Regions.



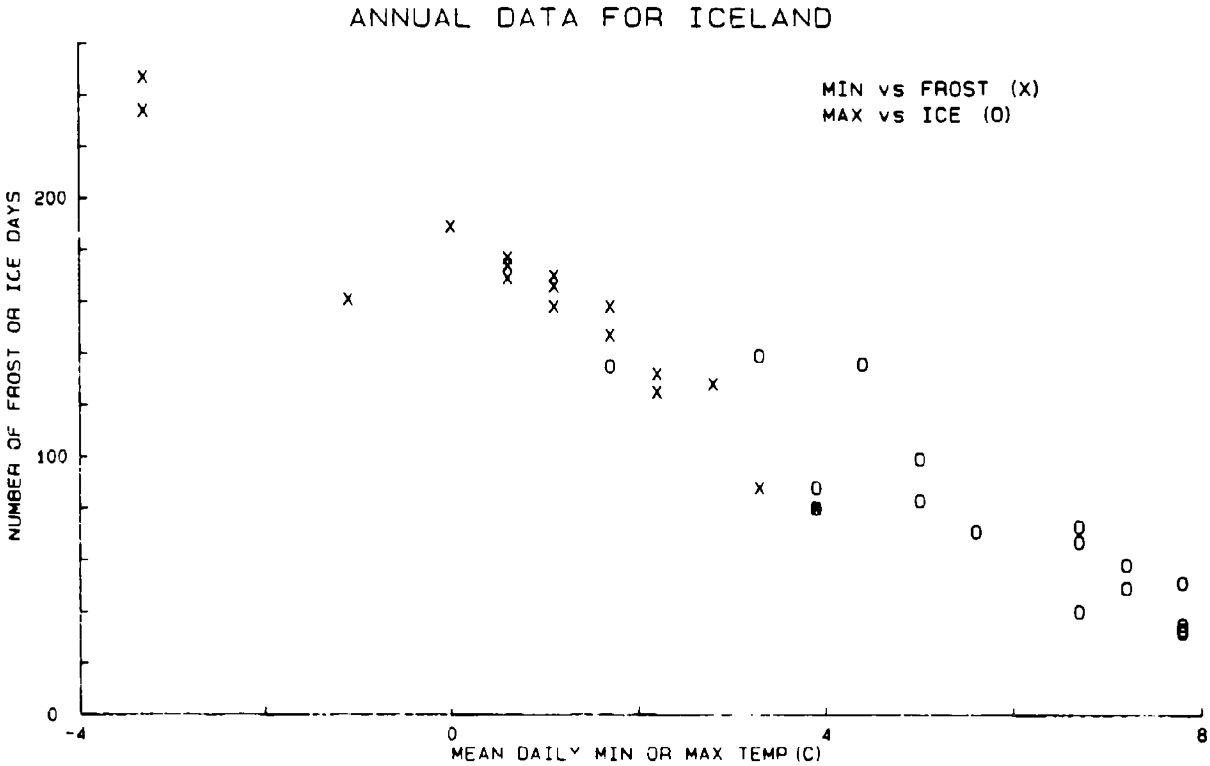
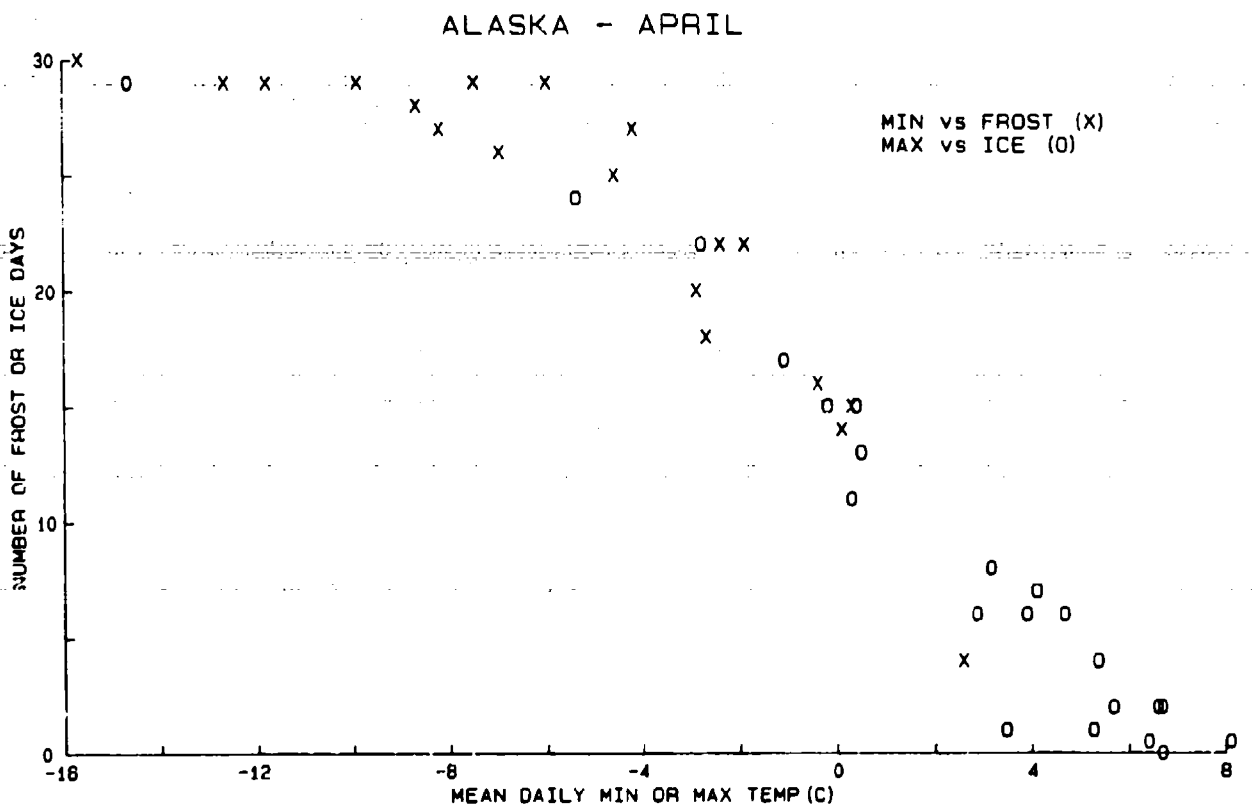


Figure 1. (continued)



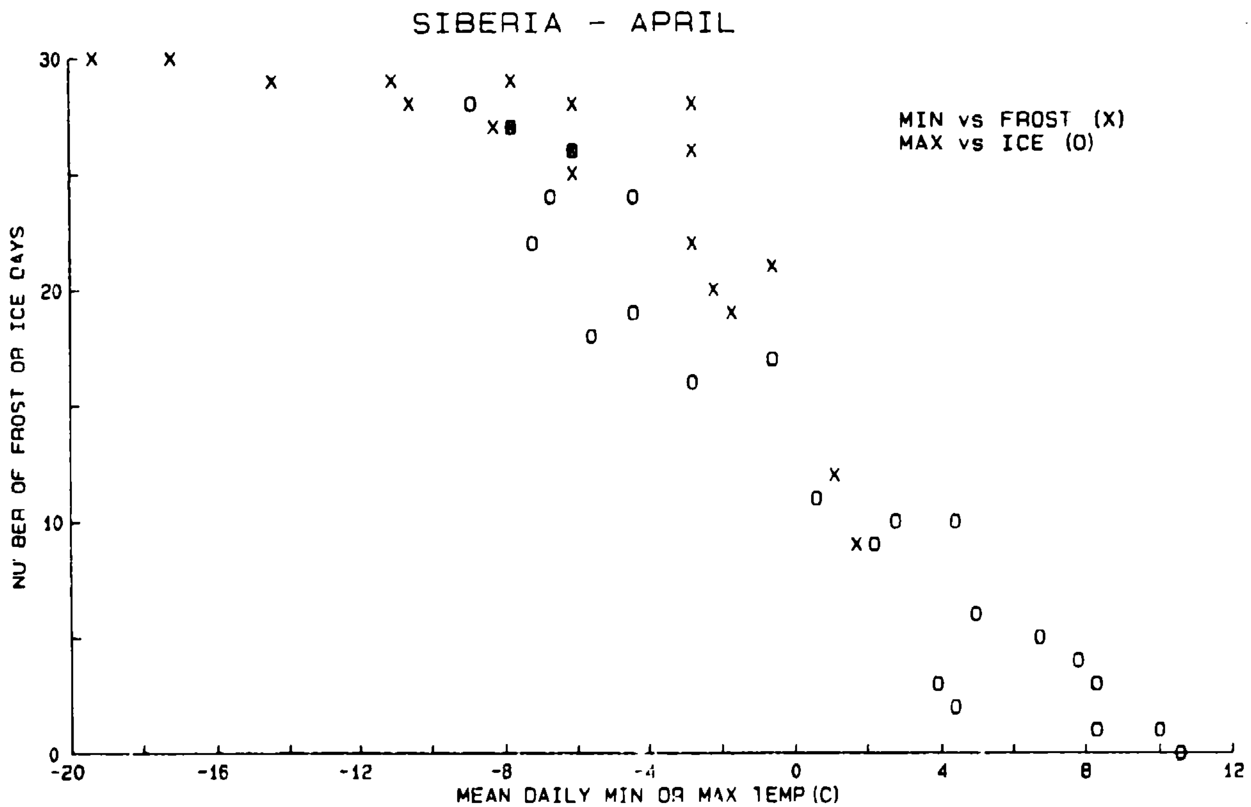
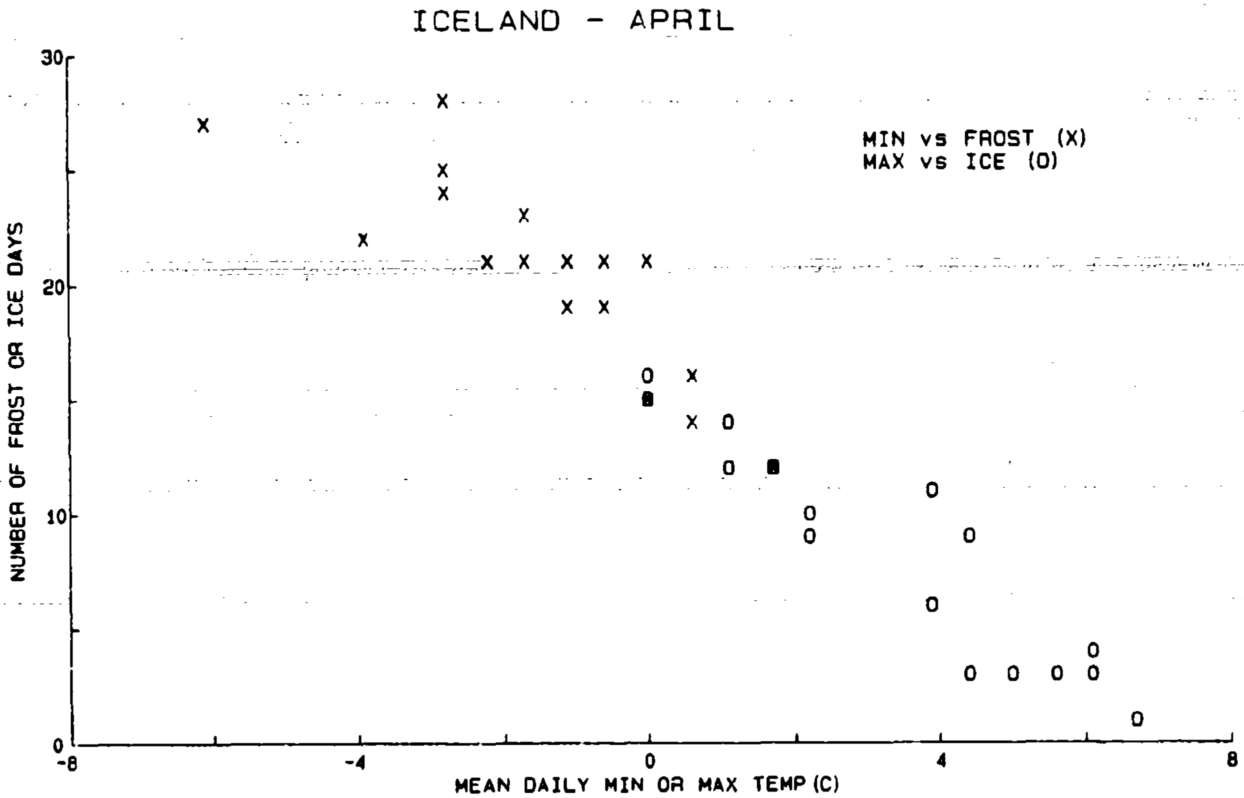


Figure 2. Selected Monthly Data.



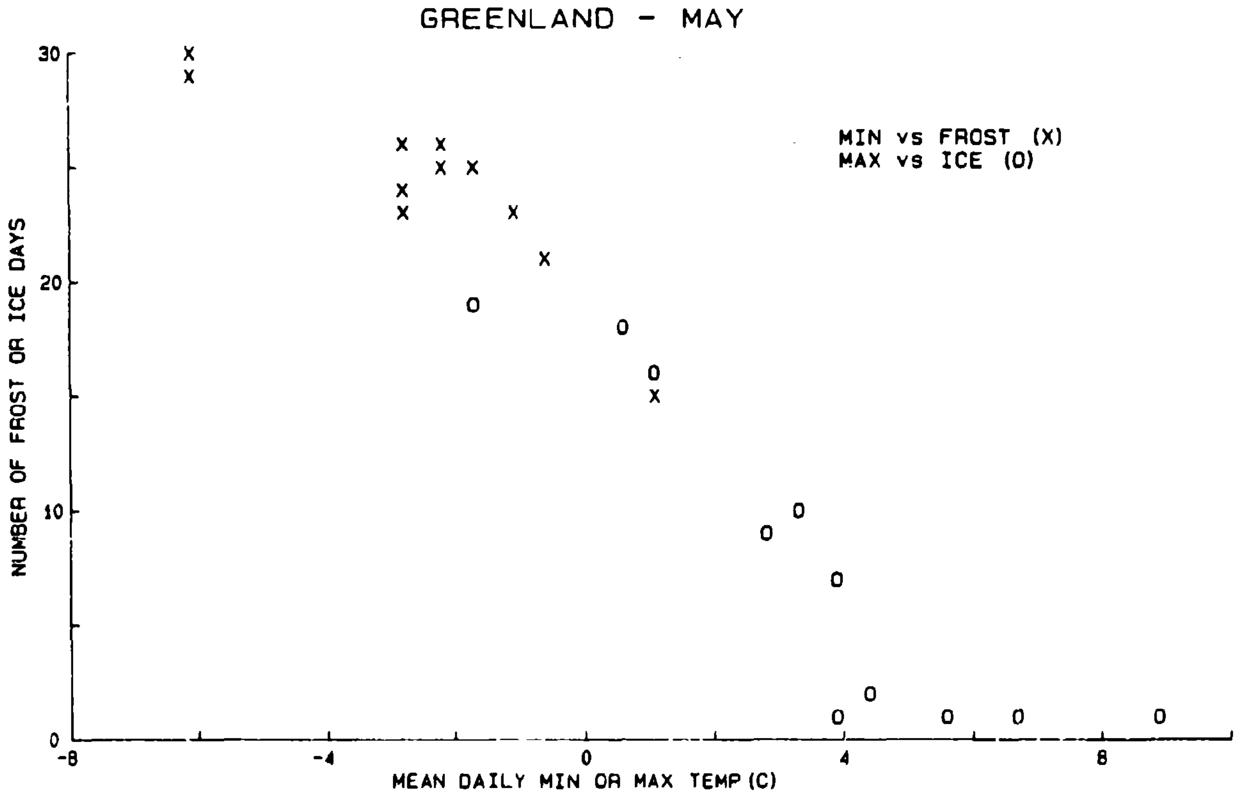


Figure 2. (continued).

Table 1. Constants a and b for monthly and annual regression equations

	$F = a_1 + b_1N$		$I = a_2 + b_2M$	
	a_1	b_1	a_2	b_2
		ALASKA		
JAN	21.1	-0.6	13.8	-1.4
FEB	19.3	-0.7	11.9	-1.3
MAR	20.2	-0.9	12.4	-1.9
APR	14.9	-1.8	13.3	-1.4
MAY	14.4	-3.1		
SEP	15.3	-2.6		
OCT	14.0	-1.8	15.8	-2.1
NOV	15.9	-1.3	12.5	-1.5
DEC	20.7	-0.7	13.0	-1.1
ANN	159	-9.7	166	-13.8
		E. SIBERIA		
MAR			16.8	-1.5
APR			14.8	-1.7
MAY	15.1	-1.9	14.6	-1.7
OCT	14.7	-1.9	15.2	-1.5
NOV			16.6	-2.1
ANN	183	-5.6	167	-6.1
		ICELAND		
JAN	19.4	-1.6	15.6	-1.4
FEB	16.7	-1.3	14.2	-2.2
MAR	17.4	-1.4	16.0	-2.1
APR	15.8	-2.1	15.9	-2.3
MAY	15.6	-2.6	9.7	-1.0
JUN	11.5	-1.7		
SEP	12.0	-1.8		
OCT	16.1	-3.0	13.9	-2.1
NOV	14.9	-1.8	14.1	-2.2
DEC	20.1	-1.2	15.9	-2.1
ANN	176	-20.2	180	-17.9
		GREENLAND		
JAN			23.5	-0.4
FEB			17.0	-0.6
MAR			18.4	-0.8
APR			14.6	-1.5
MAY	21.1	-1.4	14.6	-2.1
JUN	16.3	-2.7		
JUL	7.5	-1.4		
SEP	14.3	-2.5		
OCT			16.2	-2.8
NOV			18.7	-1.3
DEC			21.2	-0.7
ANN	227	-5.3	168	-12.4

The constants a and b may vary slightly with the period of record. If the computations are carried out for M and N in degrees Celsius (as for table 1), then the value of a equals 160 to 185 days for the annual data or 12 to 18 days for the monthly data. In other words, F (I) equals half the days per interval of time if the minimum (maximum) temperatures is 0°C. An exception is for the annual number of frost days for Greenland, with a equaling 227 days. For the annual data, the absolute value of b_1 or b_2 appears to decrease with continentality, as from 20 for Iceland, a maritime climate, to 6 for Eastern Siberia, a highly continental climate.

With respect to the monthly data, the value of a tends to be closest to 15 for the months of the transitional seasons, the spring or the fall, when diurnal freeze-thaw cycles are most frequent in this latitude (see figure 3); usually the colder the month, the higher the value of a, the warmer the month, the lower the value of a. If no constants are given in table 1 for a given month, then the percent of frost or ice days is either 0 or 100 due to the relatively warm or cold temperatures. In the computations of the monthly data the number of frost (ice days) were limited to $1 < F(I) < (n-1)$, where n = total number of days per month.

A comparison between the observed and the estimated annual number of frost days or of ice days for test stations is given in table 2. Values of r^2 for the quality of fit between the observed and estimated frequencies were $>$ 0.8 for each set of stations.

FREEZE-THAW DAYS

The number of freeze-thaw days, Z, per given interval of time (information not available in climatic summaries) may be found by a variety of methods, as by direct counting[8] or by correlation with ΔT.[9,10] In the case of just the crossover of the freezing level, as in this study, Z is simply the difference between the number of frost days and the number of ice days, or

$$Z = F - I \tag{3}$$

For each area under consideration, the individual equations for annual F and I were first obtained by means of the appropriate constants in table 1. The annual Z may be expressed as follows:

Alaska $$Z = 14M - 10N - 7 \tag{4}$$

E. Siberia $$Z = 6(M-N) + 16 \tag{5}$$

Iceland $$Z = 18M - 20N - 4 \tag{6}$$

Greenland $$Z = 12M - 5N + 59 \tag{7}$$

A comparison between the observed and the estimated annual Z (table 2) shows somewhat greater discrepancies than in the cases of F and I, the factors on which Z depends. Values of r^2 which indicate the quality of fit between estimated Z and observed Z range from ~ 0.60 to 0.76 compared to $\gg 0.90$ for F and I (except for Iceland for which r^2 was 0.84).

Equation (5) implies that Z may be correlated directly with (M-N), i.e. ΔT for Eastern Siberia. Fraser (1959)[11] found a similar relationship for Canada, although the cycles he investigated were for a larger temperature span, -2° to $1^{\circ}C$, rather than just across the freezing level.

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[8] L. William. "Regionalization of Freeze-Thaw Activity." *Annals of the American Association of Geographers*. vol. 14, pp. 597-611, 1964.

[9] J.K. Fraser. "Freeze-Thaw Frequencies and Mechanical Weathering in Canada." *Arctic*. vol. 12, pp. 40-52, 1959.

[10] S.S. Visher. "Climatic Maps of Geologic Interest." *Bulletin of the Geologic Society of America*. vol. 56, pp. 713-736, 1945.

[11] J.K. Fraser. "Freeze-Thaw Frequencies and Mechanical Weathering in Canada." *Arctic*. vol. 12, pp. 40-52, 1959.

Table 2. Estimated and observed annual numbers of frost days, ice days, and freeze-thaw days

Station	Air Temp °C	Diurn Temp Range ΔT°C	Estimated Number: Frost Days	Estimated Number: Ice Days	Estimated Number: Freeze-thaw Days	Observed Number: Frost Days	Observed Number: Ice Days	Observed Number: Freeze-thaw Days
Alaska								
Barter Is.	-12.2	5.9	310	292	18	318	260	52
Summit WSO	-3.9	8.2	239	163	76	251	177	74
Fairbanks	-3.6	11.4	252	137	115	237	157	80
Gambell Is.	-3.4	5.6	221	174	47	256	197	59
Aniak	-2.2	9.5	228	130	98	226	142	84
Naknek	1.5	8.6	187	86	101	204	99	105
Anchorage	1.6	9.2	189	80	109	208	110	98
Cordova	3.1	8.6	171	64	107	184	53	131
Seward	4.0	6.6	152	65	87	160	62	98
Sitka	5.7	7.3	139	38	101	140	21	119
E. Siberia								
O. Chetyrekhstolbovoy	-13.6	5.0	269	240	29	288	242	46
Dzhardzhan	-12.5	7.2	269	226	43	261	220	41
Zyryanka	-11.4	8.3	266	215	51	253	213	40
Ust Yvdoma	-9.2	11.7	265	189	76	252	181	71
Guga	-3.6	17.2	247	134	113	239	145	94
Nogliki	-2.0	10.5	219	145	74	220	154	66
Sukhanovka	-0.6	10.0	210	138	72	211	149	62
Poronaysk	0.0	8.8	204	138	66	196	136	60
Grosserichi	1.2	7.7	194	134	60	188	128	60
Dolinsk	2.3	9.9	194	119	75	192	119	73
Sarychevo	2.5	5.0	179	134	45	189	110	79
Bukhta Preobrazheniya	4.2	10.5	185	105	80	161	79	82
Iceland								
Modhrudalur	0.0	6.6	243	121	122	247	139	108
Raufarhofn	2.5	3.8	164	98	66	177	88	89
Blonduos	3.4	4.5	155	76	79	166	71	95
Egilsstadhir	3.4	6.7	176	56	120	178	72	106
Saudharkrokur	3.6	5.0	154	67	87	143	63	80
Akureyri	3.9	5.6	154	56	98	158	73	85
Haell	4.2	6.1	154	47	107	170	58	112
Loftsalir	5.9	3.9	97	40	57	80	33	47
Greenland								
Thule	-11.1	8.4	342	253	89	314	242	72
Upernavik	-7.3	6.7	292	210	82	284	210	74
Jakobshavn	-4.5	6.7	264	173	91	250	183	67
Umanak	-2.8	5.6	242	159	83	253	185	67
Godthaab	-0.9	6.1	225	130	95	254	141	113
Ivgtut	0.8	7.2	214	102	112	221	105	116
Narssag	1.7	6.7	203	94	109	222	96	126

STATION MODELS OF DIURNAL FREEZE-THAW CYCLES

Station models of percent days per month with diurnal freeze thaw cycles from January to December are given for selected stations in Greenland, Alaska, Iceland, the U.S.S.R, and West Germany (See figure 3). For most of the high-latitude stations, especially those close to the Arctic Circle, the peak incidence of diurnal freeze-thaw cycles occurs during the transitional seasons of spring and fall. The stations are arranged so as to show a gradual change in pattern from an extremely cold climate as Barrow, Nord, or Polar Station where diurnal freeze-thaw cycles prevail only in summer to the the relatively warm stations of Annette or Vladivostok, which have relatively long summers with no freezing and the peak frequencies of freeze-thaw cycles in the winter. The German stations from Zugspitze (2962 m) to Munich (532 m) reflect the effect of altitude on the incidence of diurnal freeze-thaw cycles. The station model for Zugspitze is somewhat similar to that for Barrow (or Polar Station). The plots for the Icelandic stations resemble that of Fichtelberg (or Brocken). At Vladivostok, despite the low latitude, January and December are too cold for freeze-thaw, whereas, in Iceland, freeze-thaw occurs all winter.

Another set of station models is shown in figure 4. This time the abscissa is the mean monthly temperature, however, the ordinate is the same as that of figure 3, namely the average percent days per month with freeze-thaw. In general, for a given station, the daily freeze-thaw cycles per month tend to increase as the mean monthly temperature approaches 0°C. The frequencies per given temperature vary from one station to another. Nevertheless, certain of the models may sometimes serve several stations or groups of stations.

Station models of this type have also been obtained for numerous other stations in the high and mid-latitudes. A few of these models, as well as an equation that provides curves that approximates some of the data in figure 4, have been given previously.[12] See Appendix for the equation. The utility of the models in figure 4 is the ready comparison of freeze-thaw regimes among different stations and/or climates.

The temperature limits for the freeze-thaw regime, as well as the peak amplitude, are climate dependent. For a highly continental station, as Verkhoyansk (not shown), the freeze-thaw temperature regime extends from about + 16 to -16°C with an amplitude of about 68 percent at about 0°C. Most stations in Iceland have an amplitude of about 40 to 50 percent with a positive temperature range of about 10°C. Cold Bay, Kodiak, and Annette in Alaska have freeze-thaw regimes similar to stations in Iceland. On the other hand, interior stations in Alaska have much higher amplitudes, about 65 to 80 percent as Fairbanks, McGrath, and Gulkana, with temperatures ranges from 12 to -16°C. For a number of stations in Greenland, the plots (not given) show much greater irregularities of pattern than for Iceland or Alaska, possibly because of the relatively short periods of record.

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[12] R.L. Wexler, "A General Climatological Guide to Daily Freezing Conditions: Frost Days, Ice Days, and Freeze-Thaw Days." U.S. Army Corps of Engineers, Fort Belvoir, Virginia. ETL-0287, AD-A116 771, 1982.

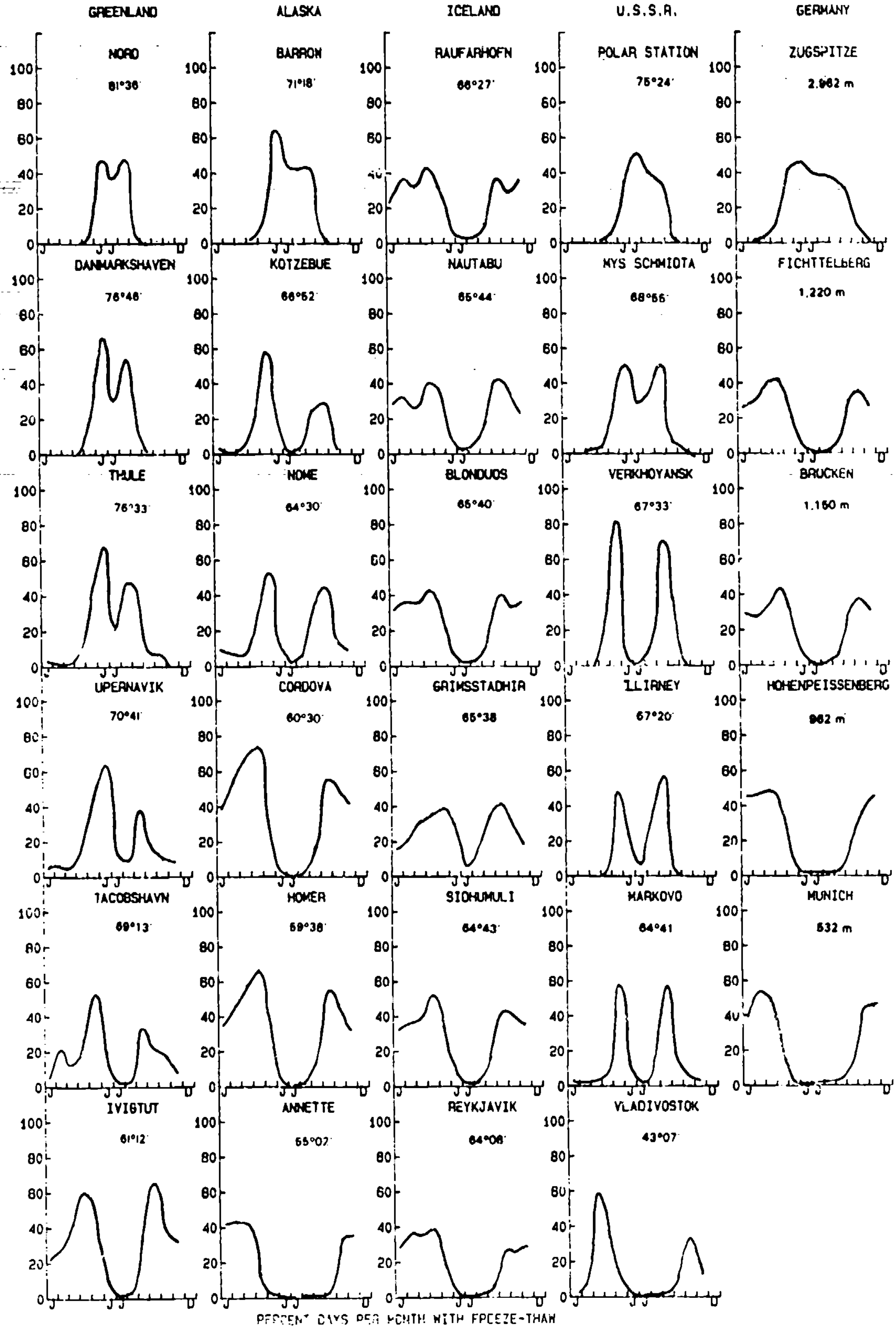

Figure 3. Percent days per month with freeze-thaw

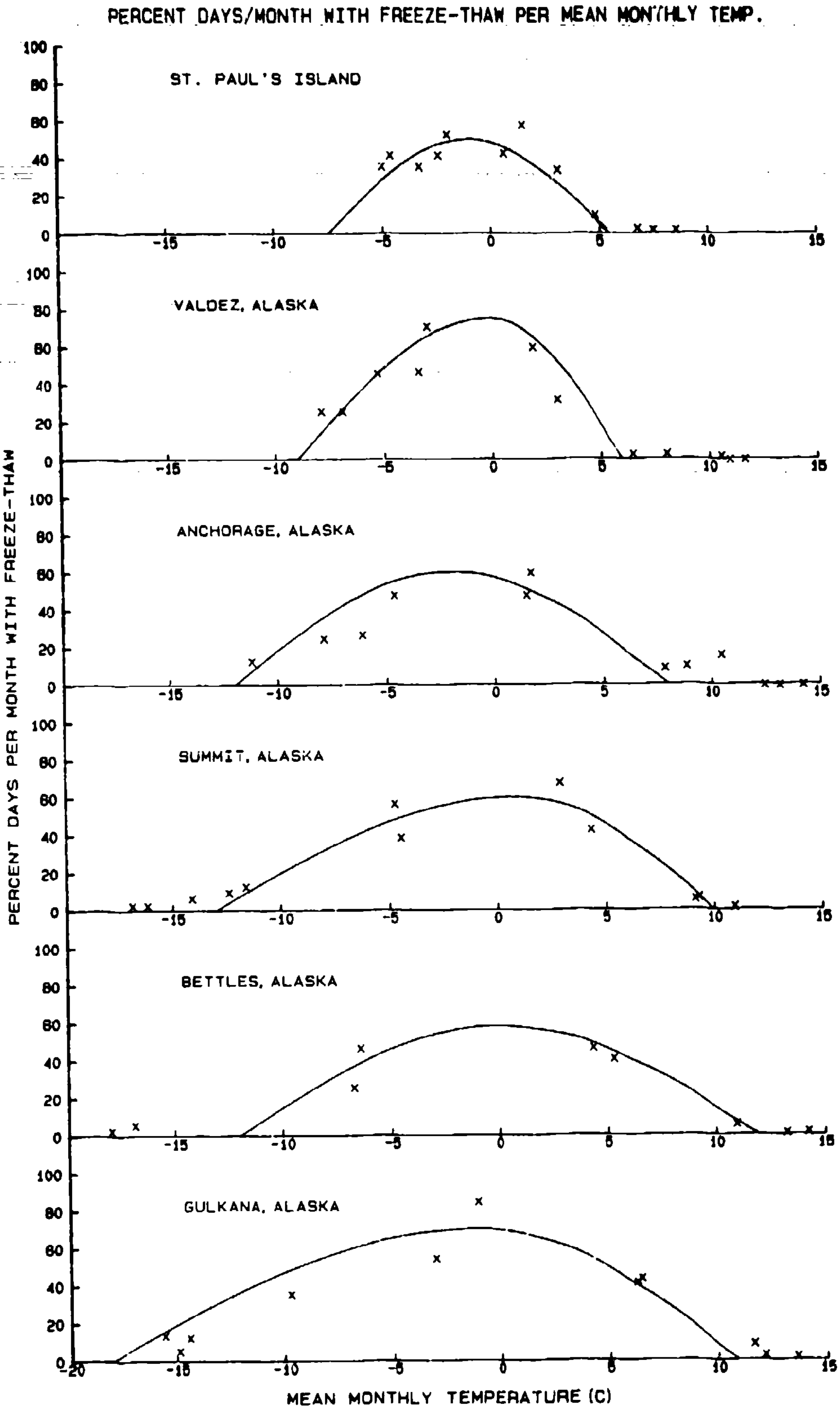

Figure 4. Percent days per month with freeze-thaw per mean monthly tempature

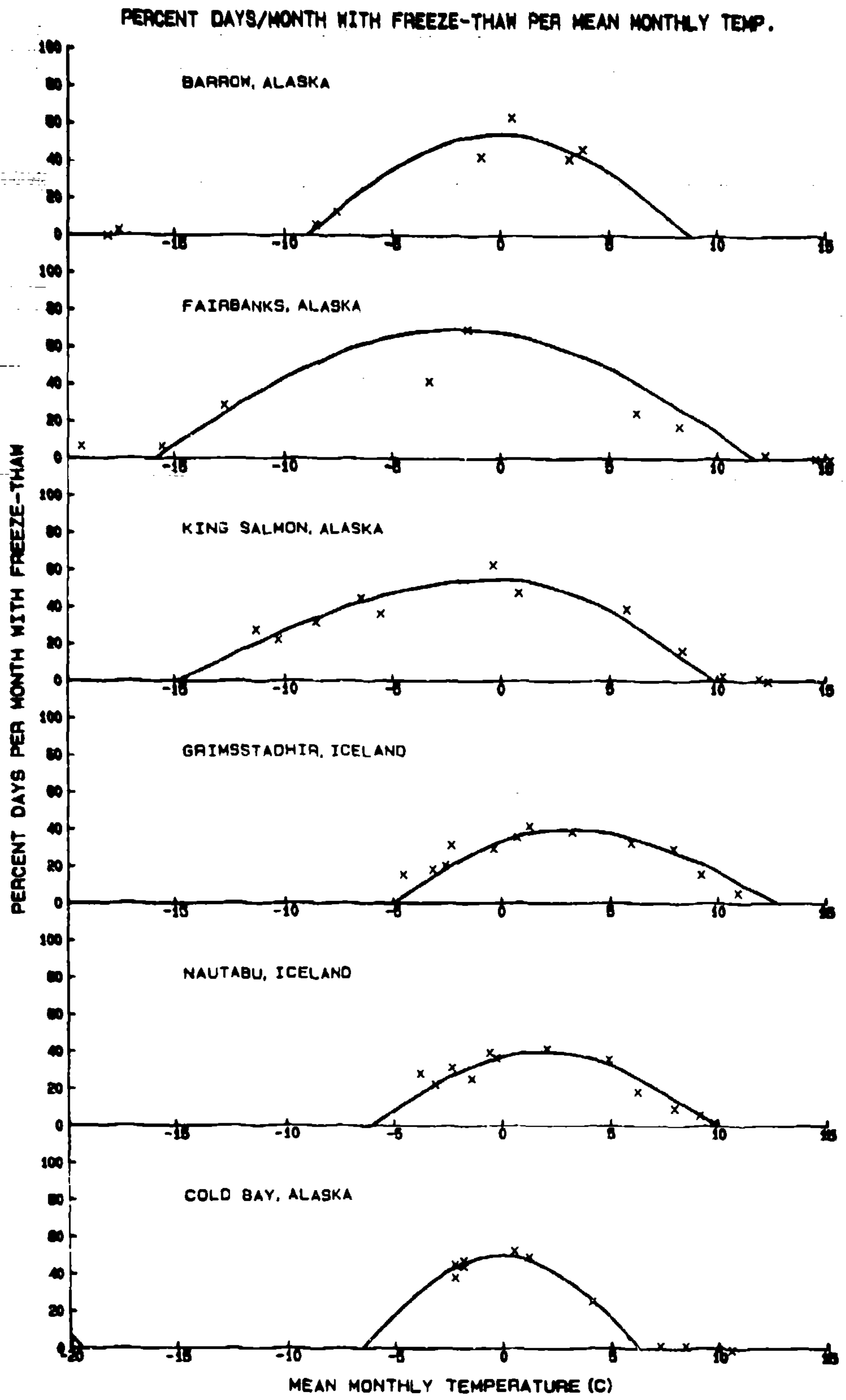

Figure 4. (continued).

CONCLUSIONS

Several mathematical and graphical models were presented for estimating the frequencies of frost days, ice days, and freeze-thaw days per month or year for stations in Alaska, Eastern Siberia, Iceland, and Greenland. Once linear regression equations are determined for the derivation of frost days and ice days, respectively, per network of stations, these equations are then applicable to any site within the area, given only the mean daily minimum and the mean daily maximum temperatures for the site. The frequencies of diurnal freeze-thaw cycles then may be readily obtained from the difference between the frequencies of the frost days and the ice days.

Two types of station models were provided, the first the conventional annual cycle of monthly freeze-thaw and the second, the same data plotted per mean monthly temperature. The percent freeze-thaw for a given temperature varies from one station to another. Although the models tend to be distinctive, each depending on latitude (solar elevation), altitude, continentality, and local conditions, nevertheless certain of the models may be used to represent groups of stations.

The study shows that diurnal freeze-thaw cycles may not necessarily be derived from mean temperatures; essential parameters are the mean daily minimum and mean daily maximum temperatures. The latter yield definitive information concerning frost days, ice days, and freeze-thaw days. As a consequence, periglacial activity might be better correlated with the mean daily minimum and/or mean maximum daily temperatures per given interval rather than mean temperature alone.

REFERENCES

Danske Meteorologiske Institute, Meteorologiske Arbog, Part 2, Greenland, 1947-1965.

Fraser, J. K. "Freeze-Thaw Frequencies and Mechanical Weathering in Canada."Arctic, vol. 12, pp. 40-52, 1959.

Hastings, A. D. "Atlas of Arctic Environment." Headquarters, Quartermaster Research and Engineering Command, Natick, Massachusetts 1961.

Hershfield, D. M. "An Investigation into the Frequency of Freeze-Thaw Cycles." University of Maryland, thesis, 1973.

Pelko, I. "Przymrozki w. Polsce W Dziesiecholccu," Reports and Studies of the Geographic Institute, University of Warsaw, Chair of Climatology, pp. 95-104.,vol. 5, 1970.

Russell, R. J. "Freeze and Thaw Frequencies in the United States." Transactions American Geophysical Union, Part I, pp. 125-133, 1943.

Shitara, H. "On Winter Days and Ice Days in Japan." Japanese Progress in Climatology, pp. 85-99, 1970.

Troll, C. "Structure Soils, Solifluction, and Frost Climates of the Earth." SIPRE Translation, 1958.

U.S. Department of Commerce "Local Climatological Data Annual Summary with Comparative Data (stations in Alaska)." 1980.

Visher, S.S. "Climatic Maps of Geologic Interest." Bulletin of the Geologic Society of America. vol. 56, pp. 713-736, 1945.

Wexler, R. L. A General Climatological Guide to Daily Freezing Conditions: Frost Days, Ice Days, and Freeze-Thaw Days. U.S. Army Engineer Topographic Laboratories Fort Belvoir, Virginia ETL-0287,April 1982 AD-A116 771

William, L. "Regionalization of Freeze-Thaw Activity." Annals of the American Association of Geographers, vol. 14, pp. 597-611, 1964.

Wilson, C. "Climatology of the Cold Regions, Northern Hemisphere II." Cold Regions Science and Engineering Monograph, 1-A3b, 1969.

APPENDIX A

A single equation for the curves that approximates most of the data in figure 4 is given by

$$y = a \sin Q \tag{A1}$$

where y = % days per month with freeze-thaw

a = amplitude of the curve (peak % monthly freeze-thaw)

$Q = \pi (T - d + b)/2b$ (Q in radians)

T_H = highest temperature associated with y = 0

T_L = lowest temperature associated with y = 0

T_a = temperature at amplitude a

$b = b_1$ or b_2 (see below)

$b_1 = T_H - T_a$

$b_2 = T_a - T_L$

d = departure from 0° C for maximum y

If the curve is symmetrical about the peak percent frequency (y = a), then $b = b_1$ for the entire curve, otherwise $b = b_1$ and/or b_2 in turn, b is always positive. For the unsymmetrical plot, then

$$Q_1 = \pi (T - d + b_1)/2b_1 \qquad T \geq T_a$$

$$Q_2 = \pi (T - d + b_2)/2b_2 \qquad T \leq T_a$$

Table A1 lists the constants for equation (A1) for the plots in figure 4. First, the plots were drawn manually, and the constants a, d, b_1 and or/b_2 estimated. The final curves in figure 4 were then generated by equation (A1). The results, although somewhat arbitrary where data points are few, seem to fit the coastal stations or the more moderate climates somewhat better than interior stations as Fairbanks or Gulkana. The higher the values of a and b_1 or b_2, the more continental the climate. Valdez appears to be somewhat of an exception, with its high a of 75 and low values of b_1 and b_2 of 6 and 8. From plots, as in figure 4, freeze-thaw regions may be readily compared among stations over the entire globe.

TABLE A1 Constants for Equation (A1)

Stations in figure 4		a	d	b_1	b_2
4a)	Barrow	50	0.0	7.5	
	Fairbanks	61	-2.5	13.5	
	King Salmon	55	0.0	11.0	15.
	Grimsstadhir	45	2.5	10.0	10.
	Natabu	45	1.0	8.0	
	Cold Bay	50	0.0	6.5	
4b)	St. Paul's Island	50	-1.0	6.5	
	Valdez	75	0.0	6.0	8
	Anchorage	60	-2.0	10.0	
	Summit	60	1.0	9.0	15.
	Bettles	58	0.0	12.0	
	Gulkana	70	-1.0	12.0	17.

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